# An Analysis of Cloud Absorption During ARESE II (Spring 2000)

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## Introduction

In early spring 2000, Atmospheric Radiation Measurement (ARM) Program researchers held an intensive operational period (IOP) at the ARM Southern Great Plains (SGP) site. This IOP had several objectives, one of which was to was to re-evaluate (with redundant measurements wherever possible) absorption by low-level stratoform, optically thick water clouds.

A previous experiment, known as ARM Enhanced Shortwave Experiment (ARESE), found cases where clouds appeared to have absorbed considerably more shortwave energy than could be explained by any radiative transfer model. This unexplained absorption has been termed "anomalous absorption." The October 30, 1995, case, in particular, found absorption of approximately 100 $W/m^2$ greater than could be predicted by the best available models.

This paper presents comparisons of the absorption from fairly simple one-dimensional simulations with measurements of absorption obtained from a combination of ground-based and aircraft-mounted hemispherical broadband radiometer. Comparisons are shown for several days in the ARESE II field campaign; the results are remarkably consistent.

The comparisons indicate that the measured absorption does exceed the model calculations, but only by approximately 20 $W/m^2$. It is unclear at this time whether this difference represents true "anomalous absorption."

## Overview of Modeling

The radiative transfer calculations were made with SBDART using approximate cloud boundaries from radar and Lidar, a constant surface albedo, a single-mode drop size distribution ($7^{th}$ order gamma function) and a standard profile (US 62) of atmospheric pressure, temperature, relative humidity, ozone, etc. This profile is very close to that measured by radiosondes launched at this time. The model calculations were constrained in two ways:

1. The model was run for a fixed effective radius (re) and the cloud liquid water path (LWP) was allowed to change such that the calculated broadband shortwave flux at the surface matched the mean of the surface measurement Solar Infrared Station (SIRS) C1 data).

2. The model was run with the LWP fixed to values retrieved from microwave radiometery and re was allowed to change such that the calculated broadband shortwave flux at the surface matched the mean surface measurement. (Thus far, we have only applied this approach to the March 3 case.)

## Overview of Comparisons

During the experiment, the U.S. Department of Energy (DOE) Twin Otter aircraft flew in a "daisy-like" pattern centered on the ARM SGP Central Facility (CF). The measurement approach in this experiment was to use a single aircraft with repeated passes over a ground site. The first step of this analysis was to divide the flight pattern into "legs," as depicted in Figure 1.

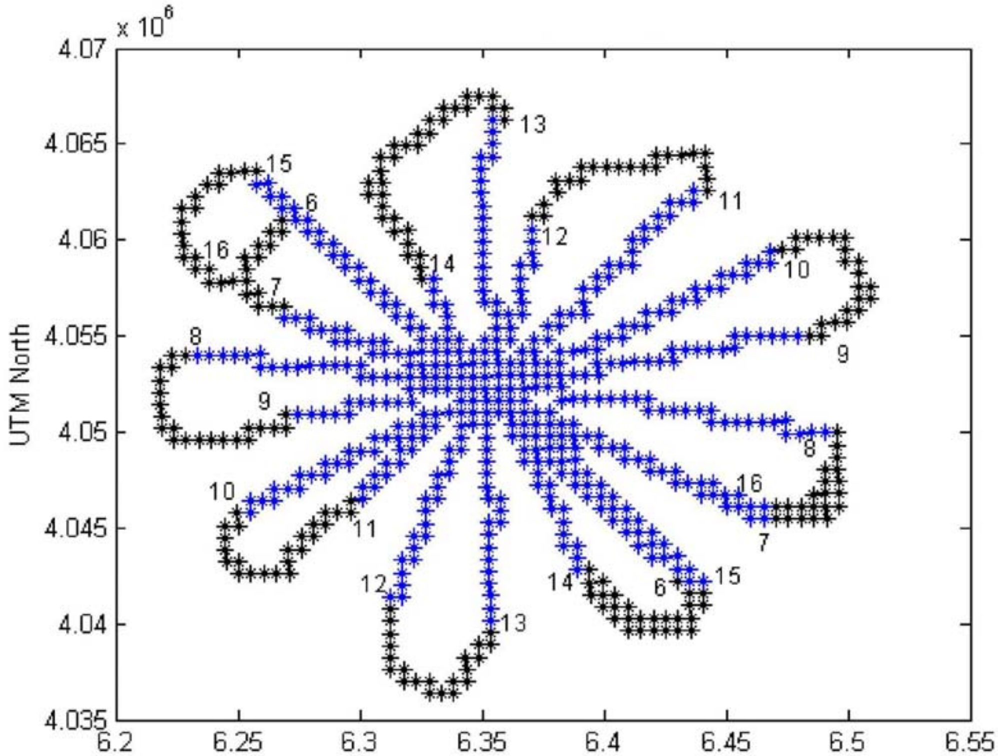


**Figure 1**. ARESE II "daisy-like" flight pattern of the DOE Twin Otter aircraft for the March 3, 2000, cloudy-sky case. Blue crosses mark the regions or legs of this particular flight selected for processing. The selections were made based on when the aircraft was flying reasonably level as determined from the recorded aircraft pitch and roll measurements. Above cloud flight legs selected for processing are noted with numbers 6-16.

For each leg, a simulation was run as described above. Figures 2 - 4 compare the simulations and measurements for flights on March 3, March 21, and March 29; Figure 5 summarizes the results for the three cases.

The uncertainty bars in these figures represent one standard deviation of the value over the set of good legs.

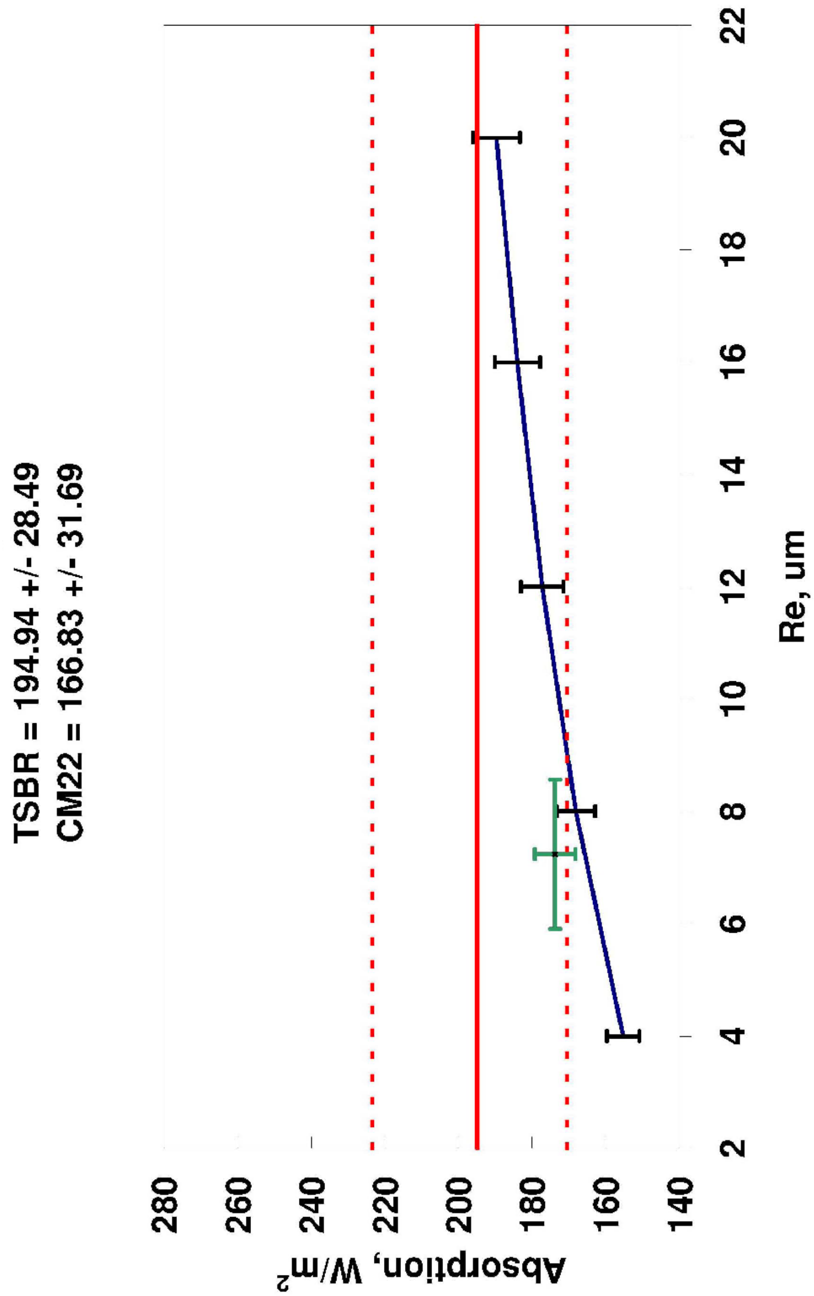


**Figure 2**. Column absorption for ARESE II cloudy-sky flight March 3, 2000. Dashed and solid red lines represent the standard deviations and average value, respectively, for the Total Solar Broadband Radiometer (TSBR). Blue diamonds represent the SBDART values for different inputs of Re. Standard deviation bars reflect the variability of the model absorption values for individual legs of each flight. The green crosshair represents the SBDART values calculated using LWP inputs from Microwave Radiometer measurements. The uncertainty of the LWP results in an uncertainty in re as reflected by the horizontal crosshair. The vertical crosshair gives the calculated absorption variability for individual flight leg intervals.

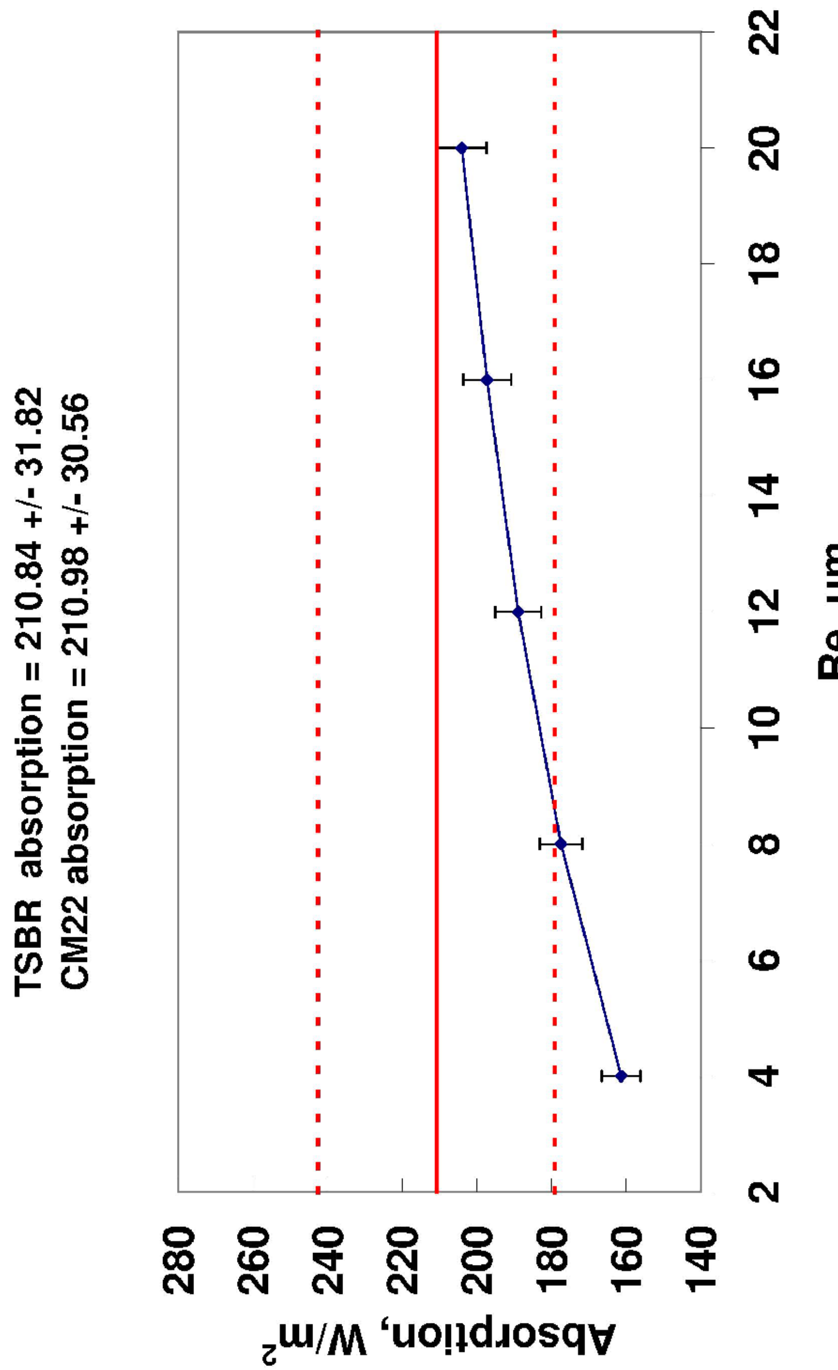


**Figure 3**. Column absorption for ARESE II cloudy-sky flights March 21, 2000. Dashed and solid red lines represent the standard deviations and average values respectively for the TSBR radiometer. Blue diamonds represent the SBDART values for different inputs of Re. Standard deviation bars reflect the variability of the model absorption values for individual legs of each flight.

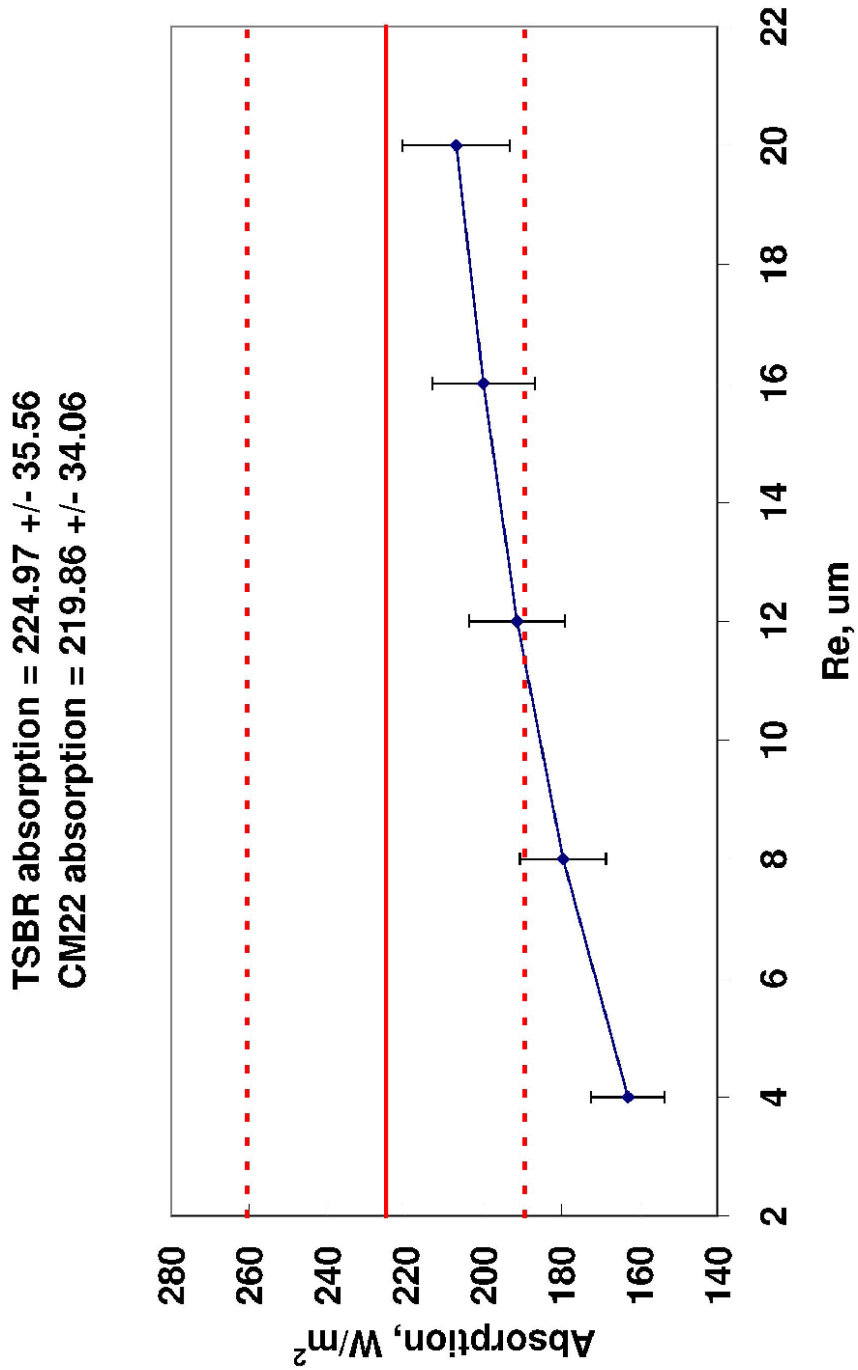


**Figure 4**. Column absorption for ARESE II cloudy-sky flights March 29, 2000. Dashed and solid red lines represent the standard deviations and average values respectively for the TSBR radiometer. Blue diamonds represent the SBDART values for different inputs of Re. Standard deviation bars reflect the variability of the model absorption values for individual legs of each flight.

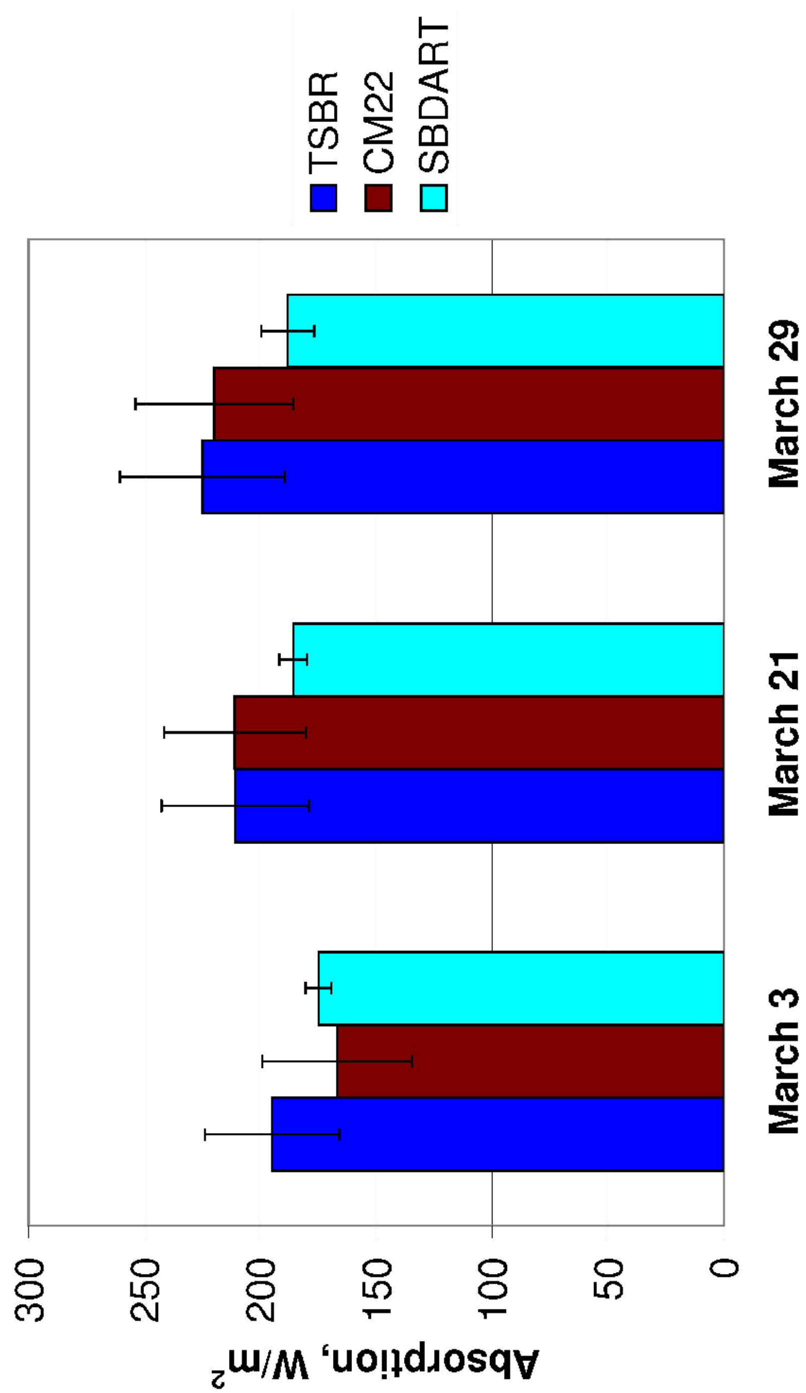


**Figure 5**. ARESE II March 2000, cloudy-sky flights. Comparison of calculated column absorption from two radiometer measurements (TSBR and CM22) and model results (SBDART) for 3 cloudy-sky ARESE II flights. Standard deviation bars reflect the variability of the absorption values for individual legs of each flight.

We used only those flight legs during which no upper-layer clouds were detected, based on low values and large standard deviations in the aircraft measurements. Also, legs before 17.6 Universal Time Coordinates on March 3 were removed because of a mid-level (probably ice) cloud observed by the cloud radar over the CF prior to this time.

## Discussion

Ultimately the purpose of the ARESE II Experiment was to re-evaluate (with redundant measurements wherever possible) absorption by low-level stratoform, optically thick water clouds. The comparisons shown here indicate that for the three-day period examined, the measured absorption consistently exceeds the model calculations, but only by approximately 20 W/m$^2$. One is tempted to suggest that this 20 W/m$^2$ is anomalous absorption, but before such can be stated unequivocally one must first understand the uncertainties and possible sources of error.

There are several important areas that need to be addressed.

1. Uncertainty or error in the individual measurements.

That is, the absorption is calculated by taking the difference of at least four individual radiometers. This is not to criticize the tremendous efforts undertaken by the measurement groups, but to recognize the difficulty in achieving an accuracy of 20 W/m$^2$ in the combined aircraft and ground measurements.

2. Uncertainty due to spatial separation of the ground and aircraft instruments.

Some initial work undertaken by Marshak, Wiscombe, Oreopoulos, and others suggests that this uncertainty does not rise to the level of 20 W/m$^2$. We look forward to following their research on this topic.

3. Errors in the model calculations.

Our research group currently believes the accuracy in the model calculations of codes such as RAPRAD, SBDART, and SHDOM is less than 20 W/m$^2$. We are investigating this factor closely.

4. Uncertainties in model inputs.

It should be stressed that what makes "anomalous absorption" anomalous is that it exceeds model-computed absorption within the range of uncertainty in the model inputs. The results presented here are for a fairly simple model. A more complete sensitivity study, which considers factors such as the likely increases in absorption due to drizzle (especially for the cases of March 21 and March 29) and the effect of inhomogenities in the cloud structure may be required.

## Acknowledgement

We would like to thank Tim Tooman and Fransico Valero for providing their measurement data and for the many frank discussions regarding the processing and calibration of these data. We would similarily like to thank Joe Michalsky for his work in calibrating and collecting the surface shortwave flux data.